Toward Developing an Expert GIS for Damage Evaluation after an Earthquake (Case study: Tehran)

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ABSTRACT

In an earthquake disaster, having proper estimation about destructed buildings and the degree of destruction, can considerably facilitate decision-making and planning for disaster managers. Using this information, the managers can estimate disaster area and number of victims to determine and allocate required resources. Scientific studies and historical data show that the faults around Tehran, the capital of Iran, are capable to create strong earthquakes which would bring the largest damages in the world history to the city. So it is necessary to be prepared for a rapid and knowledge-based response to such an earthquake. Therefore, development of a knowledge-based model to estimate destruction of buildings is ongoing. The model is going to be developed by using different spatial data obtained from the buildings and its environment in Tehran. This paper outlines the initial results of this research.

Keywords

Earthquake, emergency response, expert system, GIS, knowledge-base

INTRODUCTION

Due to the time-sensitive nature of disasters, rapid and reliable decision-making has a significant impact on managing disasters. Such decision-making highly requires proper information on current emergency situation. Meanwhile, estimation on disaster area and number of victims are essential information that a manager may need for proper decision-making. As a result, production of a possible destruction map is indeed of a high value to managers. Tehran, the capital of Iran with a population of more than ten million (Census ministry of Iran, 2004), is built on a network of faults with high risk to earthquake. Historically, Tehran has an earthquake return period of 150 years and no earthquake has occurred in 175 years. Having mentioned that, Tehran is threatened by a strong earthquake which will bring large damages and casualties to the city. So, the disaster management community should prepare itself for responding to such a huge disaster. One of the aspects of the mentioned preparedness relates to having proper tools and models to estimate disaster area and number of victims for preparing initial plans.

In this research, estimating damage level in the case of earthquake is based on expert systems. Expert systems are computer applications which embody some non-algorithmic expertise for solving certain types of problems. In these models, different spatial data such as the earthquake center and magnitude, distance of building from the center, soil type and geological characteristics of the ground between the center and building, structural characteristics of the building and the age of the building and number of floors are used. The data has been integrated in an expert GIS to estimate human and physical seismic vulnerability in a part of Tehran.

GIS FOR SEISMIC RISK MONITORING

A fundamental principle of risk assessment is that risk due to natural hazards such as earthquakes, hurricanes and floods is location dependent. The process of risk assessment involves hazard assessment and vulnerability analysis. The probability of earthquake occurrence varies depending on location and local site conditions which also plays a vital role in determining the intensity of the earthquake. Zoning of hazard prone regions is a common practice. The vulnerability of buildings, other critical structures and population is dependent on their exposure to the hazard, which varies from location to location. The spatial characteristics of hazard and vulnerability justify the application of mapping and spatial technologies such as GIS in the risk assessment process.

A Geographical Information System is an organized collection of hardware, software geographical data and personnel designed to efficiently capture, store, update manipulate, analyze and display all forms of geographically referenced information (Lavakare and Krovvidi A., 2001). However, the term GIS could also be used to refer to the technology involved in capturing, storing, manipulating and analyzing spatial information.

Analysis and simulation of diverse seismic scenarios are also made in an integrated fashion, taking into account all the information available in databases. For the analysis of earthquake effects, three hypotheses can be considered (Bouhafs et al, 1997): deterministic hazard - an earthquake happened in a location where previous events have been recorded, probabilistic hazard - an earthquake produced in a location statistically chosen from records of extended periods of time, respectively 100, 1000 or 2500 years, and user-defined hazard - an earthquake simulated in a location desired by the user, with defined Peak Ground Acceleration (PGA) and response spectra maps.

GIS support may be used for all the disaster phases however, what we are concerned with here is the use of GIS for spatial data handling for input to an expert system. This includes assigning appropriate properties to every parcel, defining building codes depending on center of earthquake, etc.

EXPERT SYSTEMS

Expert system is a computer program that performs difficult, specialized tasks at the level of a human expert. Because of the reliance of these programs on varied types of knowledge, these programs are also known as Knowledge-Based Systems. Developers of expert systems strive to provide systems with the ability to:

1. Mimic the reasoning capability of human experts;

2. Deal with incomplete and imprecise knowledge;

3. Explain and provide a rationale for conclusions;

4. Provide alternate options for consideration;

5. Provide wider distribution and access to scarce expert knowledge; and

6. Provide systematic and consistent application of knowledge.

Expert systems have a number of major system components and interface with individuals in various roles (Figure 1). The major components are as follow:

- Knowledge base: a declarative representation of the expertise, often in IF THEN ELSE rules;
- Working storage: the data which is specific to a problem being solved;
- Inference engine: the code at the core of the system which derives recommendations from the knowledge base and problem-specific data in working storage;
- User interface: the code that controls the dialog between the user and the system;

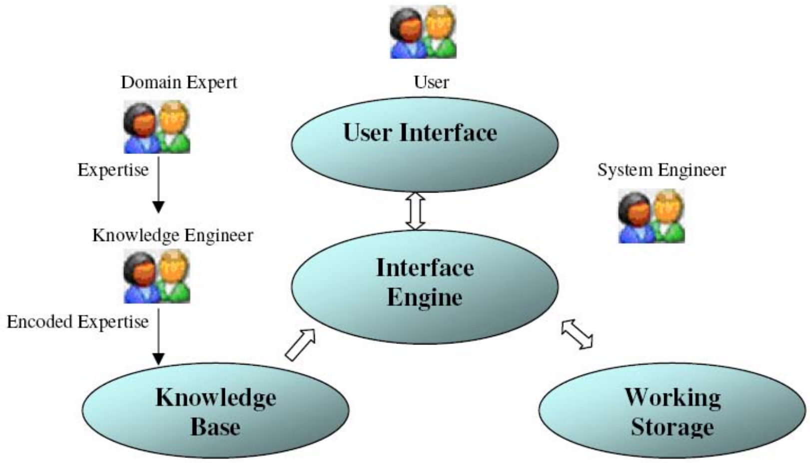

Figure 1. Expert system components and human interfaces

Many expert systems are built with products called expert system shells. The shell is a piece of software which contains the user interface, a format for declarative knowledge in the knowledge base, and an inference engine. The knowledge engineer uses the shell to build a system for a particular problem domain.

EXPERT SYSTEM FEATURES

There are a number of features which are commonly used in expert systems. Some shells provide most of these features, and others just a few. Customized shells provide the features which are best suited for the particular problem. The major features are as follow:

- Goal driven reasoning or backward chaining: an inference technique which uses IF THEN ELSE rules to repetitively break a goal into smaller sub-goals which are easier to prove;
- Coping with uncertainty: the ability of the system to reason with rules and data which are not precisely known;
- Data driven reasoning or forward chaining: an inference technique which uses IF THEN ELSE rules to deduce a problem solution from initial data;
- Data representation: the way in which the problem specific data in the system is stored and accessed;
- User interface: that portion of the code which creates an easy to use system;
- Explanations: the ability of the system to explain the reasoning process that it used to reach a recommendation.

Each of these features has its properties. In this paper we considered different rules and knowledge to obtain proper risk statistics for buildings in different locations based on center of earthquake and other parameters investigated in the following sections. The expert system was developed in this project according to the major concepts known in artificial intelligence fields for developing standard expert systems. The following list is summarizing the steps followed to develop the system:

- *Identification of the problem:* Estimation on disaster area and number of victims is essential information that a manager may need for a proper decision-making. As a result, production of a possible destruction map is indeed of a high value to managers.

- *Knowledge abstraction and representation:* In expert systems, knowledge means the information a computer needs before the expert system can behave intelligently. It needs to be abstracted from the knowledge source and represented in unique ways that a computer can manipulate efficiently. There are two dominant ways supported by most expert system shells to represent knowledge. The first one is a rule-based representation. This method uses IF condition THEN action statements to represent knowledge. When the condition in IF part is satisfied or matched, that rule will be fired and the action specified by the THEN part is then triggered. The second knowledge representation method is frame-based. It uses a network of classes and instances (also called nodes or frames) connected by relations and organized into a hierarchical structure. Frame-based representation is able to clearly document information about the domain in a natural way and modularize the information, permitting relative easy system expansion and maintenance. This method is also fully supported by the power of object-oriented programming languages such as information encapsulation and inheritance.

- *User Interface:* User interface links the user and the knowledge-based expert system. Generally, user interfaces obtain information that is needed to solve a particular problem by asking the user to answer questions or prompting the user to provide relevant information in preformatted way. The system is designed to be used at different levels of user sophistication.

- *Database component:* A database that helps to fill gaps in the required input data of the model is presented. Database in expert system help the user to store, save and manage data.

- *Algorithmic structure and component analysis program:* The proposed model is generating parameters from various techniques. The expert system should be able of evaluating and selecting techniques and relating the user to the GIS, geostatistics method and parameter estimation model.

- *Knowledge base component:* The knowledge base component provides means for integrating the data base component and the analysis/ algorithmic component with rules needed for decision-making. Expert rules were either provided by the authors, or derived from published sources.

Reasons for developing and implementing expert systems vary, but most often are characterized by one or more of the followings:

1. Human expertise is lost due to retirement, transfer, etc.
2. Average practitioners perform inconsistently;
3. Tasks are not repetitive (algorithmic), but require extensive thought each time; and
4. Human experts are scarce, and a knowledge bottleneck exists.

IMPORTANT DIMENSIONS OF KNOWLEDGE

- Data: Flow of captured events or transactions

- Information: Data organized into categories of understanding

- Knowledge: Concepts, experience, and insight that provide a framework for creating, evaluating, and using information. Can be tacit (undocumented) or explicit (documented)

DATA COMPONENTS FOR EARTHQUAKE HAZARD

A diverse range of data including the earthquake center and magnitude, distance of building from the center, soil type and geological characteristics of the ground between the center and building, structural characteristics of the building ,the age of the building and number of floors are used (Figure 2). After occurrence of an earthquake, the center and the magnitude of the earthquake are two initial data that can be available. The magnitude of earthquake in any location is different from the magnitude at the center. It differs and generally decreases when the distance between a certain point and the earthquake center increases. Different factors such as soil type and distance from the center effect on the value of magnitude on a certain point. To obtain this effect and the magnitude in any place, some formulas called attenuation relationships are used. Common parameters that can be calculated by these formulas are PGA (Peak Ground Acceleration), PGV (Peak Ground Velocity) and PGD (Peak Ground Displacement). These formulas are developed based on empirical or theoretical studies. By using different spatial data and relationship between them we proposed a model that helps to assessment the amount of damage on buildings based on their properties and spatial logics as rules.

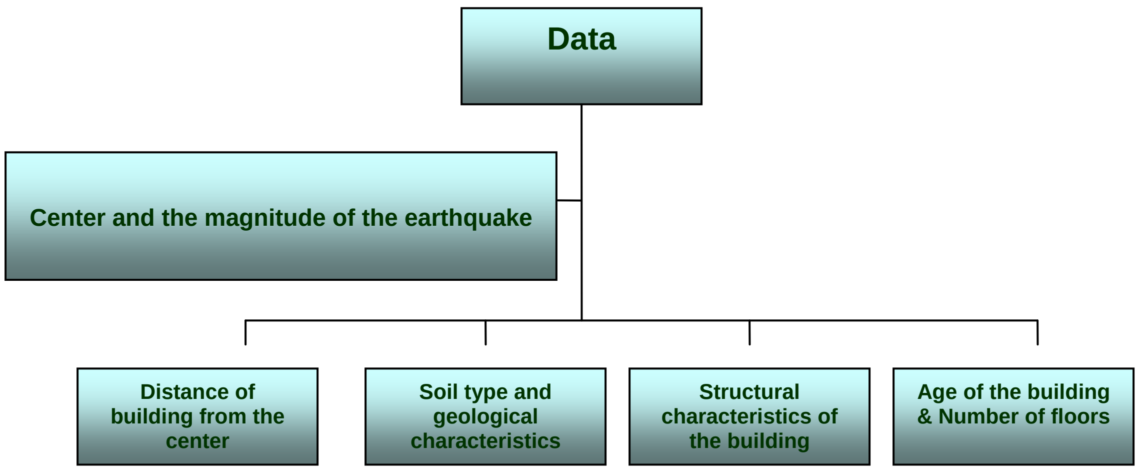

Figure 2. Structure of data used in the paper

THE PROPOSED METHODOLOGY

To estimate destruction for an individual building, firstly, the earthquake magnitude at the location of a given building should be calculated using attenuation relationships in term of PGA, PGV or PGD. In the second step by using some properties such as structural characteristics, age of buildings, number of floors, soil type, geological characteristics and distance of building from the center of the earthquake the expert system and its defined rules should be obtained. Knowledge bases in expert system are based on collections of the rules. These rules are constructed by encoding the experience and knowledge of a group of experts. In following we illustrate identified building with its properties in the system (Figure3).

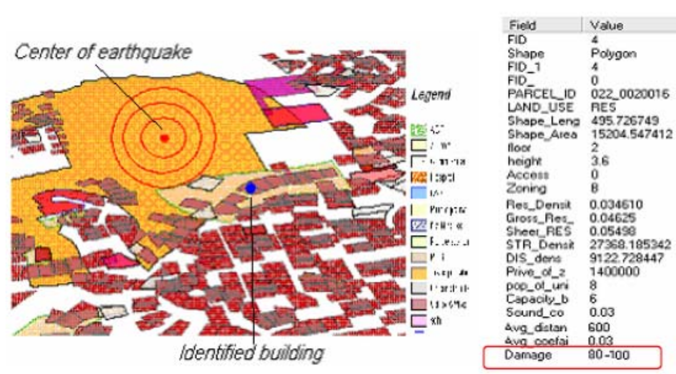

Figure 3. Identified building and its properties in the system

Weighting the properties

This study should classify the properties into classes of high and low priority of weight to obtain destruction probability. This is done through a two step weighting process. In the first step, each property is externally weighted based on degree of importance in destruction probability. In the second step, each property is internally weighted. For instance, it should be considered a maximum limit for distance of the center of the earthquake; the buildings that are out of predefined range are excluded from the procedure. Each property can take a relative weight between zero to one, implementation as well as engineering judgment. Similarly, from the geological aspect, each of geological characteristics is weighted based on the facts if the soils has a low penetration factor or is hard to dig or is close to clay area or not. From Structural characteristics point of view, the buildings are weighted based on the kind of their structure. For example the buildings where have been built from steel, destruction probability is less than the ones are from wood. Therefore, the highest weights are assigned based on the lowest destruction probability (Figure 4).

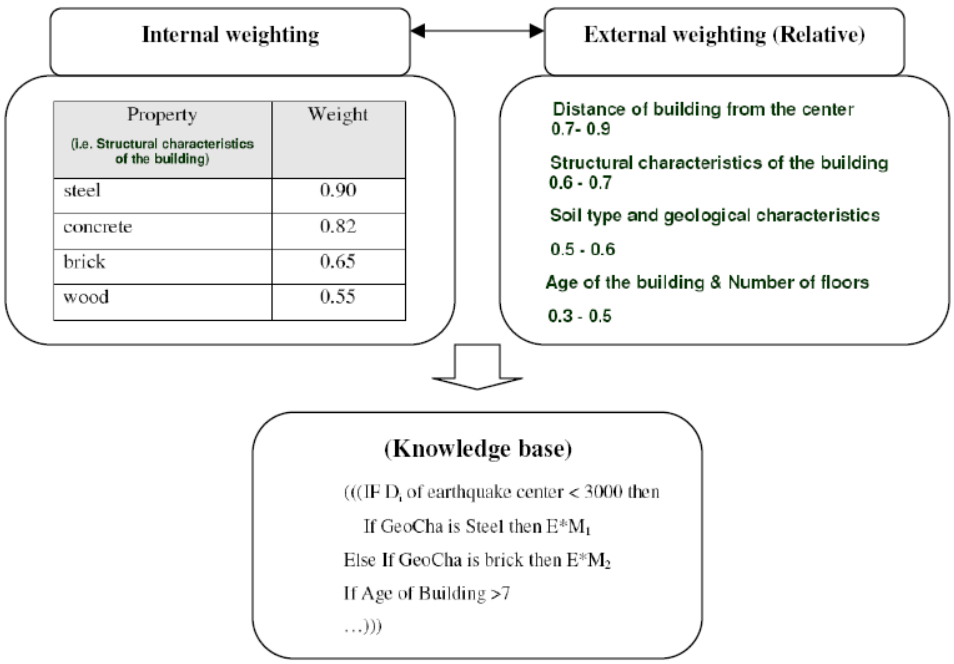

Figure 4. External and Internal weighting schema

For a data driven system, the system must be initially populated with data, in contrast to the goal driven system which gathers data as it needs it. Figure 5 illustrates the forward chaining system that used in this paper. The forward chaining system starts with the data (i.e. properties of each building) and uses the rules to derive a result in this case probability destruction.

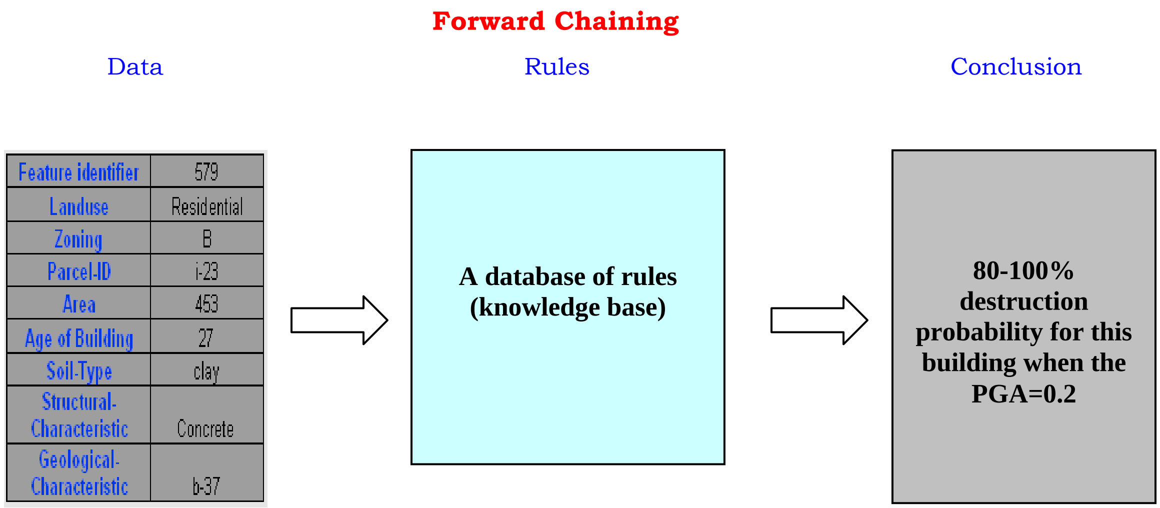

Figure 5. Structure of methodology used

User Interface

The acceptability of an expert system depends to a great extent on the quality of the user interface. The easiest to implement interfaces communicate with the user through a form as illustrated in figure 6.

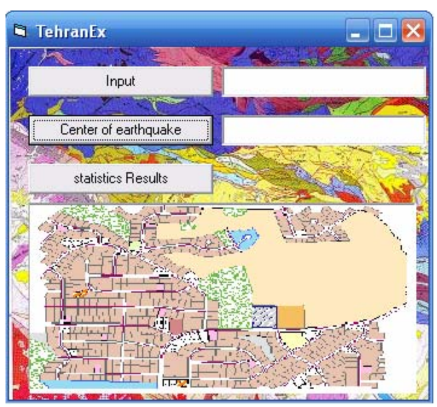

Figure 6. User interface in the system

CONCLUSION

In an earthquake disaster, having proper estimation about destructed buildings and the degree of destruction, can considerably facilitate decision-making and planning for disaster managers. Therefore development of a knowledge-based model to estimate destruction of buildings is ongoing. In this paper, in seismic destruction of buildings as well as the role of expert system in developing an appropriate model for this purpose were studied. In addition, the method of developing initial results of the proposed model for damage evaluation of buildings in Tehran was defined. The model is being completed on the basis of the aforementioned method. In these models, different spatial data such as the earthquake center and magnitude, distance of building from the center, soil type and geological characteristics of the ground between the center and building, structural characteristics of the building and the age of the building are used. The initial results achieved verify the seismic vulnerability in a part of Tehran. Further development of the model to include various analysis tools for improving the system is the next step of this research.

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